CARBOHYDRATE CONCENTRATIONS OF APPLES AND PEARS AS INFLUENCED BY IRRADIATION AS A QUARANTINE TREATMENT[1]

S.R. DRAKE[2], L.G. NEVEN[3] and
P.G. SANDERSON[4]

USDA, ARS-TFRL
1104 N. Western Ave.
Wenatchee, WA 98801

Accepted for Publication March 19, 2003

ABSTRACT

Commercially packed Fuji and Granny Smith apples and Anjou and Bosc pears were exposed to irradiation treatments using a gamma beam 650 source containing cobalt-60 at doses of 150, 300, 600 and 900 Gy. After irradiation, apples were stored for 30, 60 and 90 days, while pears were stored for 30 and 90 days in ambient atmosphere at 1C. Analysis of carbohydrate concentrations of the fruit flesh were conducted during and after each storage period. Irradiation treatment did not influence the total carbohydrate or individual sucrose, glucose, fructose, or sorbitol concentrations in either apples or pears, regardless of the cultivar. Carbohydrate concentrations changed in both apples and pears as storage time progressed and these changes were cultivar dependent. Total carbohydrates and glucose, fructose and sorbitol concentrations increased, and sucrose decreased in apples as storage progressed. Total carbohydrates and fructose increased; whereas, sucrose, glucose and sorbitol concentrations decreased in Anjou pears as storage progressed. Total and individual carbohydrate concentrations decreased in Bosc pears as storage progressed from 30 to 90 days.

[1] Appreciation is expressed to the Washington State Tree Fruit Commission for grant funds partially supporting this study.

[2] Corresponding author. Research Horticulturist, USDA, ARS-TFRL, 1104 N. Western Ave., Wenatchee, WA 98801.

[3] Research Entomologist, USDA, ARS, 5230 Konnowac Pass Road, Wapato, WA 98951.

[4] Research Plant Pathologist, WSTFRC, 1719 Springwater Ave., Wenatchee, WA 98801.

Journal of Food Processing Preservation **27** (2003) 165–172. *All Rights Reserved.*

INTRODUCTION

Export of agricultural commodities to foreign markets is of major interest to the United States. Fumigation of fruit products with methyl bromide (MeBr) to meet quarantine requirements imposed by foreign countries for insect pest control has met with varying degrees of success, due primarily to injury to the host fruit. At the present time, regardless of the problems associated with fumigants, MeBr is the only treatment accepted by a number of countries that constitute important markets for fruits and vegetables. The future of MeBr as a quarantine treatment is in doubt (Stephens 1996). Restrictions on the use of MeBr were imposed by both the Montreal Protocol and the U.S. Clean Air Act for all but preshipment and quarantine uses, which are exempt. In addition, the price of MeBr has soared. In 1992, the price for a 100 lb. tank was about $5.00; as of February 2002, the price increased to $720 (Pest Fog, TX). In addition, the amount of MeBr being used world-wide for preshipment and quarantine purposes rose to over 22% of total uses; this is in stark contrast to the assessed total use of 2% in 1992. The exemption for preshipment and quarantine uses will be reassessed in the next meeting of the Montreal Protocol, probably resulting in further restrictions in the use of this fumigant. To continue to export agricultural commodities, an acceptable alternative to MeBr must be developed.

Treatment of fresh produce with irradiation is a viable alternative for MeBr. Research is being conducted on irradiation of fruits and vegetables for disinfestation of both insects and decay causing microbes. Loss of quality in fresh produce after irradiation is reported (Maxie *et al.* 1971). However, sweet cherries (Drake *et al.* 1994; Drake and Neven 1997; Eakin *et al.* 1985; Eaton *et al.* 1970; Kader 1986), blueberries (Miller *et al.* 1994), apples (Olsen *et al.* 1989) and winter pears (Drake *et al.* 1999) treated with up to 1000 Gy suffered little or no quality loss. Currently the FDA allows 1000 Gy or less on fruits and vegetables (Kader 1986). Eakin *et al.* (1985) reported that codling moth (*Cydia pomonella* L.) control can be achieved with a dose of 250 Gy.

Despite research indicating that the use of irradiation is advantageous, as a quarantine treatment, with little or no quality losses and approval by the FDA, there is still public concern. A major concern being raised with irradiation is that it may affect the chemical or nutritional aspects of food (Oder 2001; PCCMEEP 2000; Worth 2000). This research was conducted to determine the influence of irradiation at levels sufficient to meet quarantine on the carbohydrate concentrations of selected cultivars of apples and pears during post-irradiation storage.

MATERIALS AND METHODS

Irradiation treatments were conducted at Pacific Northwest National Laboratory, Richland, WA using a gamma beam 650 source containing cobalt 60. Distance of the boxed fruit from the source was adjusted to provide a dose rate of 8.32 Gy/min. Exposure time was varied to attain doses of 150, 300, 600 and 900 Gy. Dose was determined using a commercially available small volume ionization chamber made from air equivalent plastic. Apple and pear fruit used as controls were not irradiated, but were transported and held under equivalent temperature, environmental, and handling conditions as irradiated fruit.

Commercially packed Fuji and Granny Smith apples, size 88, from three grower lots were obtained from a Wenatchee, WA warehouse after 90 days of controlled atmosphere storage (1% O_2 and 1% CO_2 at 1C). Apples were transported to the irradiator the following day. After irradiation treatment, the fruit were transported to Wenatchee, WA and placed in ambient atmosphere storage at 1C, for an additional 30, 60 and 90 days. Carbohydrate concentrations of the treated fruit were determined 30, 60 and 90 days after irradiation.

Commercially packed, size 100, US No. 1, Anjou and Bosc winter pears were obtained from three North Central Washington warehouses. The pears were held in ambient atmosphere storage from 7 to 45 days at 1C prior to selection for irradiation. Selected pears were held one to two days at 1C prior to transportation to the irradiation facility. After irradiation the pears were transported to Wenatchee, WA and placed in ambient atmosphere storage at 1C. Carbohydrate concentrations of the treated fruit were determined 45 and 90 days after irradiation.

Carbohydrate analyses were conducted on a composite of ten apples or pears for combinations of irradiation treatments, storage and replication. A longitudinal slice was removed from each individual fruit within 4 h after removal from storage and juiced. After juicing, a 5 mL aliquot of the juice was frozen at -10C. When a sufficient number of juice aliquots were collected, carbohydrate analysis was conducted.

Frozen juices were first thawed and filtered through a 0.45 μm membrane and degrees Brix were determined prior to HPLC analysis. Degrees Brix were determined using a tabletop American Optical, Abbe type refractometer. The HPLC system consisted of a Waters 510 pump, a Waters 710B Wisp autosampler, a Waters differential refractometer and a Bio-Rad column heater set at 80C. An Aminex HPX-87C monosaccharide analysis column was selected and fitted with a Carbo-C microguard column (Bio-Rad Laboratories). The mobile phase was 0.01% reagent grade calcium chloride prepared with deionized water and the flow rate was 0.8 mL/min. Carbohydrate standards were prepared by adding 2.0 g each of reagent grade sucrose, glucose, fructose or sorbitol to a 100 mL volumetric flask and diluting to volume with deionized water.

Injection volumes for carbohydrate standards and fruit juices were 10 μL. Data were analyzed using MSTAT-C (1988) in a completely randomized design with a factorial treatment arrangement using irradiation levels as the main plot and storage time as the subplot. Means were separated following significant F tests using Tukey's HSD test.

RESULTS AND DISCUSSION

Public concern that irradiation implies a negative impact on the quality of fruits and vegetables is widespread. Popular articles abound on the questionable safety of the use of irradiation, even at minimal doses to meet quarantine requirements. In this study, using irradiation at approved doses ($\leq$ 1000 Gy) produced no consistent changes in the total carbohydrate concentration of either Fuji and Granny Smith apples (Table 1), or Anjou and Bosc pears (Table 2). There were subtle differences in the individual carbohydrates of apples, but no changes were observed as dose rate was increased from 150 to 900 Gy. Similarly, the amount of both total carbohydrates and individual sucrose, glucose, fructose and sorbitol sugars remained constant in apples and pears as the amount of irradiation was increased from 150 to 900 Gy. Low dose irradiation ($\leq$ 900 Gy) can be used as a quarantine treatment in apples and pears without loss of carbohydrates.

Changes in total and individual carbohydrates as storage time increased was noted in both Fuji and Granny Smith apples (Table 1). Total carbohydrates increased ($>$0.50 mg/g) in both apple cultivars as storage time progressed from 60 to 90 days of CA storage. Individual fructose and sorbitol concentrations increased in both apple cultivars as storage time progressed. Glucose increased in Fuji apples as storage time elapsed, but remained constant in Granny Smith apples. Sucrose concentration decreased in both apple cultivars as storage time progressed by about the same amount as the increase in total carbohydrates. An increase in total carbohydrates and individual carbohydrates glucose and sorbitol, and a decrease in sucrose of Gala apples observed as storage time progressed is previously reported (Drake and Eisele 1999). Fructose concentration of Gala apples did not change during 90 days of storage.

Differences in total and individual carbohydrates for pears as storage time progressed was not as consistent between cultivars as the changes between apple cultivars (Table 2). Changes in both total and individual carbohydrates of Anjou and Bosc pears after 45 and 90 days of storage was cultivar dependent. Total carbohydrates increased in Anjou pears as storage time elapsed from 45 to 90 days. Fructose concentration was the only individual carbohydrate to increase during storage of Anjou pears. Sucrose, glucose and sorbitol decreased during storage of Anjou pears. Bosc pears lost not only total carbohydrates during

TABLE 1.
CARBOHYDRATE CONTENTS OF FUJI AND GRANNY SMITH APPLES AS INFLUENCED BY IRRADIATION TREATMENT SUFFICIENT TO MEET QUARANTINE REQUIREMENTS AND STORAGE TIME

Carbohydrates (mg·g^{-1})

	Total CHO		**Sucrose**		**Glucose**		**Fructose**		**Sorbitol**	
	Fuji	G. Smith	Fuji	G. Smith	Fuji	G. Smith	Fuji	G. Smith	Fuji	G. Smith
Irradiation Dose (Gy)										
0	14.73a^z	10.66c	2.62ab	2.06a	3.25ab	2.83a	8.60a	5.47a	0.60a	0.29b
150	14.69a	11.32ab	2.46ab	2.52a	3.23b	2.85a	8.42a	5.59a	0.58ab	0.36a
300	15.18a	10.63c	2.69a	2.20a	3.29ab	2.70a	8.61a	5.44a	0.59ab	0.31ab
600	14.79a	11.47a	2.43ab	2.45a	3.35ab	2.92a	8.50a	5.74a	0.51ab	0.36a
900	14.70a	10.85bc	2.13b	2.22a	3.59a	2.80a	8.50a	5.51a	0.50b	0.32ab
Storage Time (days after irradiation treatment)										
30	15.10b	11.93b	2.87a	2.73a	3.36b	3.12a	8.50b	5.84b	0.57a	0.21c
60	13.50c	8.53c	2.39b	1.87c	3.02c	2.16b	7.78c	4.27c	0.47b	0.26b
90	15.86a	12.50a	2.30b	2.27b	3.65a	3.18a	9.30a	6.54a	0.62a	0.51a
Irradiation Dose x Storage Time										
	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

^{z}Means in a column, within radiation dose or storage, not followed by a common letter are significantly different by THSDT ($P \leq 0.05$).

TABLE 2.
CARBOHYDRATE CONTENTS OF 'ANJOU' AND 'BOSC' WINTER PEARS AS INFLUENCED BY IRRADIATION TREATMENT SUFFICIENT TO MEET QUARANTINE REQUIREMENTS AND STORAGE TIME

Carbohydrates ($mg \cdot g^{-1}$)	Total CHO		Sucrose		Glucose		Fructose		Sorbitol	
	Anjou	Bosc	Anjou	Bosc	Anjou	Bosc	Anjou	Bosc	Anjou	Bosc
Irradiation Dose (Gy)										
0	12.17a[z]	13.21a	1.20a	2.40a	1.49a	1.35a	6.82a	6.76a	3.71a	2.71a
150	10.48a	13.28a	1.04a	2.29a	1.36a	1.51a	5.81a	6.58a	3.71a	2.91a
300	10.42a	12.85a	1.07a	2.47a	1.43a	1.31a	5.75a	6.13a	3.69a	2.94a
600	11.03a	13.16a	1.00a	2.57a	1.52a	1.34a	6.17a	6.34a	3.82a	2.91a
900	11.91a	14.02a	0.80a	1.79a	1.19a	1.36a	6.43a	6.73a	3.18a	3.15a
Storage Time (days after irradiation treatment)										
30	11.05b	14.44a	1.48a	2.92a	1.99a	1.52a	5.95b	6.74a	4.44a	3.26a
90	12.36a	12.16b	1.03b	2.08b	1.04b	1.22b	6.86a	6.27b	3.71b	2.59b
Irradiation Dose x Storage Time										
	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[z]Means in a column, within radiation dose or storage, not followed by a common letter are significantly different by THSDT ($P \leq 0.05$).

storage, but individual concentrations of sucrose, glucose, fructose, and sorbitol were each decreased. Changes in total and individual carbohydrates for Bartlett were previously reported (Drake and Eisele 1999), but changes in both total and individual carbohydrates were dependent on growing district and not length of storage.

CONCLUSIONS

Quality losses in apples and pears after exposure to irradiation are reported (Drake *et al.* 1999) and related to both irradiation dose and cultivar. Loss of firmness and acidity were predominant quality losses. No quality losses have been reported for apples and pears at irradiation doses of 300 Gy or less. In this study, no loss of either total or individual carbohydrates were associated with irradiation treatment of apples or pears. Carbohydrates changed in irradiated apples and pears as storage time progressed, and these changes were cultivar dependent. Total and individual (glucose, fructose and sorbitol) concentrations increased and sucrose decreased in irradiated apples as storage progressed. Total carbohydrates and fructose increased, but sucrose, glucose and sorbitol concentrations decreased in irradiated Anjou pears as storage progressed. Total and individual carbohydrate concentrations decreased in irradiated Bosc pears as storage progressed from 45 to 90 days. Insect control can be obtained at irradiation doses of 250 Gy (Eakin *et al.* 1985). Irradiation can be used as a quarantine treatment of apples and pears with no substantial decreases in carbohydrate concentrations.

REFERENCES

DRAKE, S.R. and EISELE, T.A. 1999. Carbohydrate and acid contents of Gala apples and Bartlett pears from regular and controlled atmosphere storage. J. Agr. Food Chem. *47*, 3181–3184.

DRAKE, S.R., MOFFITT, H.R. and EAKIN, D.E. 1994. Low dose irradiation of 'Rainier' sweet cherries as a quarantine treatment. J. Food Processing Preservation *18*, 473–481.

DRAKE, S.R. and NEVEN, L.G. 1997. Quality response of 'Bing' and 'Rainier' sweet cherry to low dose electron beam irradiation. J. Food Processing Preservation *21*, 345–351.

DRAKE, S.R., SANDERSON, P.G. and NEVEN, L.G. 1999. Response of apple and winter pear fruit quality to irradiation as a quarantine treatment. J. Food Processing Preservation *23*, 203–216.

EAKIN, D.E., HUNGATE, F.P. and TINGELY, G.L. 1985. Cherry irradiation studies: 1984 Annual Report. Battelle-Pacific Northwest Laboratories. Richland, WA.

EATON, G.W., MECHAN, C. and TURNER, N. 1970. Some physical effects of postharvest gamma irradiation on the fruit of sweet cherry, blueberry and cranberry. J. Can. Inst. Food Technol. *3*, 152–156.

KADER, A.A. 1986. Potential applications of ionizing radiation in postharvest handling of fresh fruits and vegetables. Food Technol. *40*, 117–121.

MAXIE, E.C., SOMMERS, N.F. and MITCHELL, F.G. 1971. Infeasibility of irradiation of fresh fruits and vegetables. HortScience *6*, 202–204.

MILLER, W.R., MCDONALD, R.E. and MCCOLLUM, T.G. 1994. Quality of 'Climax' blueberries and low dosage electron beam irradiation. J. Food Quality *17*, 71–79.

ODER, D. 2001. *What's Wrong with Food Irradiation*. Organic Consumers Assoc., Little Marais, MN.

OLSEN, K.L., HUNGATE, F.P., DRAKE, S.R. and EAKIN, D.E. 1989. 'Red Delicious' apple response to low dose radiation. J. Food Quality *12*, 107–113.

Public Citizens Critical Mass Energy and Environment Program and the Cancer Prevention Coalition. 2000. A broken record: How the FDA legalized and continues to legalize food irradiation without testing it for safety. (www.purefood.org/irrd/executive summary).

STEPHENS, D. 1996. No replacement for methyl bromide. Fruit Grower *116*, 30–31.

WORTH, M. 2000. Shelf death: Nuked food makes it to grocery shelves. Progress Populist, May 29.